Pitching Moment of an Airfoil

Charles Keer

AE 315

Department of Aerospace Engineering

Embry-Riddle Aeronautical University, Daytona Beach, FL, 32114-3900

Introduction

A wind tunnel can give invaluable insight into the aerodynamic characteristics of any object that is tested in it. For this lab, a NACA 0012 airfoil with semi-span length of 30.94 in and chord length of 12 in was tested in a wind tunnel at different angles of attack. By measuring the lift, drag, and moments on the airfoil as it is turned through different angels of attack, the airfoil can be accurately

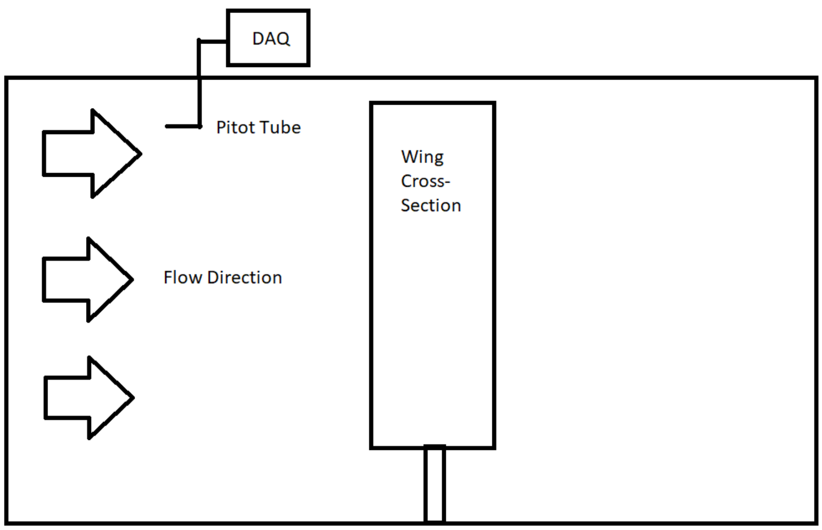

Figure 1. Schematic of experimental cross section in wind tunnel.

characterized. The experiment was performed at two velocities: 100ft/s and 150ft/s. For each trial, a "dry run" was done with the tunnel turned off to gather gravity tare data. At each velocity, a positive and negative angle sweep was done from 0 to 20 and 0 to -20 degrees respectively.

Table 1. Experimental Conditions.

Velocity	Reynolds Number
100 ft/s	7268208
150 ft/s	10892870

Results and Discussion

The by taking the lift data gathered from the lab and plotting it against the angle of attack, there is a clear indication of flow separation near the highest angles. This is seen in Figure two where there are two “loops” at either end of the datapoints. As the airfoil is turned to higher angles of attack,

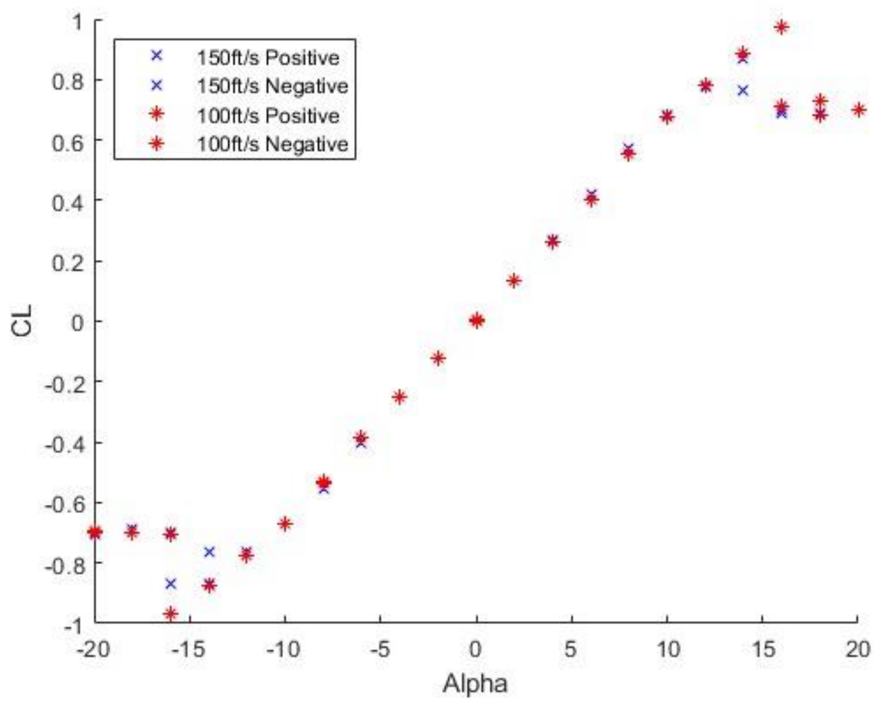

Figure 2. Lift coefficient plotted against angle of attack.

the flow will eventually separate from the wing and rapidly become turbulent. As the angle goes from -20 to 0, the flow will reattach itself and become more laminar, increasing the lift and subsequently the lift coefficient. Note how the maximum lift coefficient is at the highest angle.

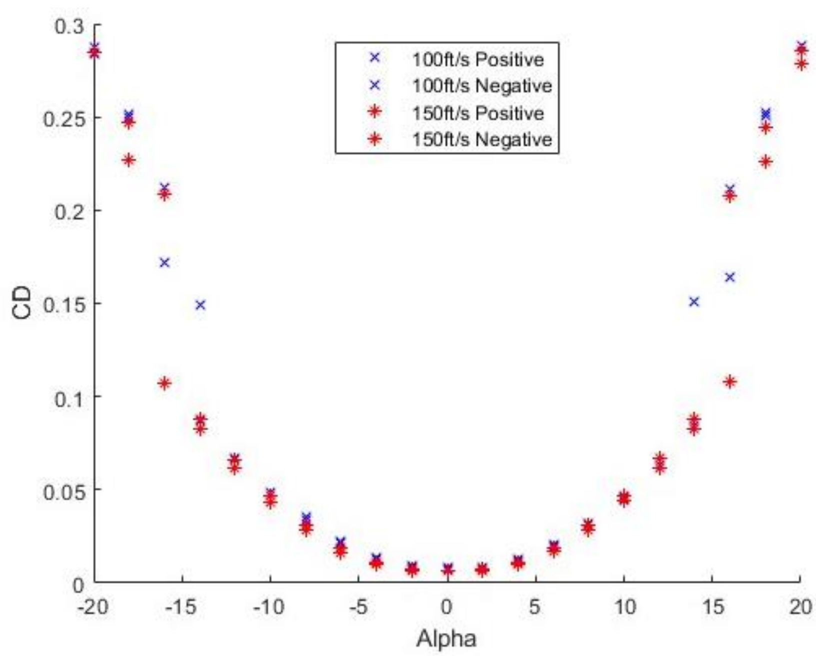

Figure 3. Drag coefficient plotted against angle of attack.

Similarly, the drag coefficient can also be found. By plotting it against the angle of attack, the lowest and highest drag coefficient can be attained. For this airfoil, the maximum occurs around 20 and -20 degrees with a CD of approximately 0.27. The lowest occurs at 0 angle of attack and is approximately 0.01. This is accurate as a more turbulent flow will have higher drag.

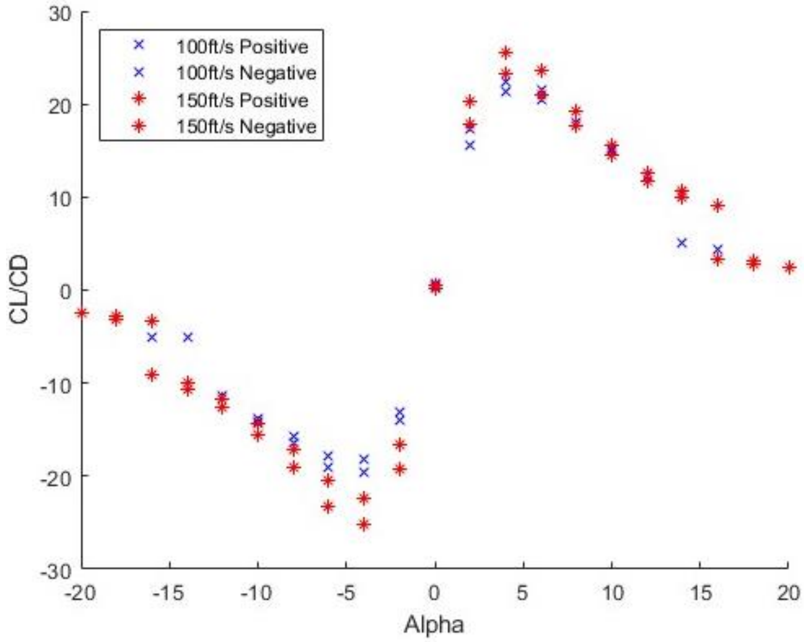

Figure 4. Lift coefficient over drag coefficient vs angle of attack.

By combining the lift and drag data, the best lift to drag ratio can be found for this airfoil. This can be found in Figure 4. The best lift to drag ratio is approximately 27 and occurs at an AOA of 4 degrees. Figure 5, which shows the lift vs drag coefficient can also be useful in characterizing

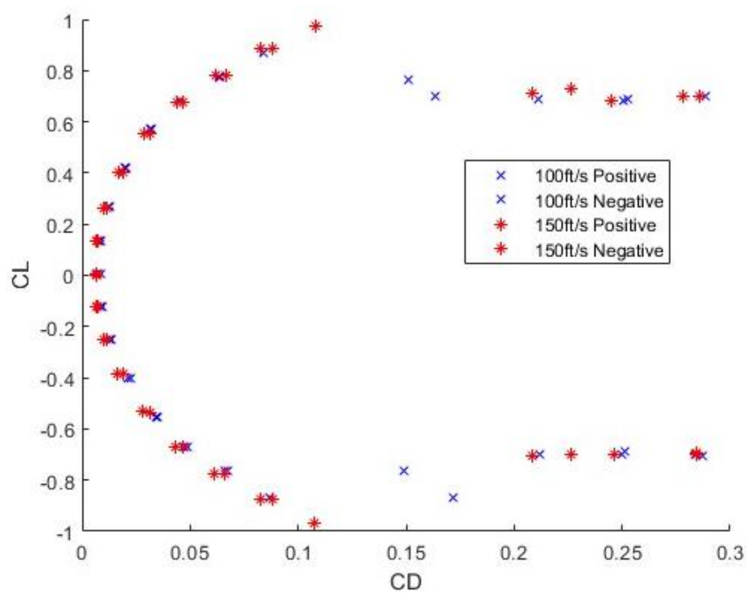

Figure 5. Lift vs drag coefficient.

the airfoil.

The pitching moment of the quarter chord is also a useful metric in the characterization of airfoils. This is the region of the airfoil that will consistently stay fixed in reference to the freestream

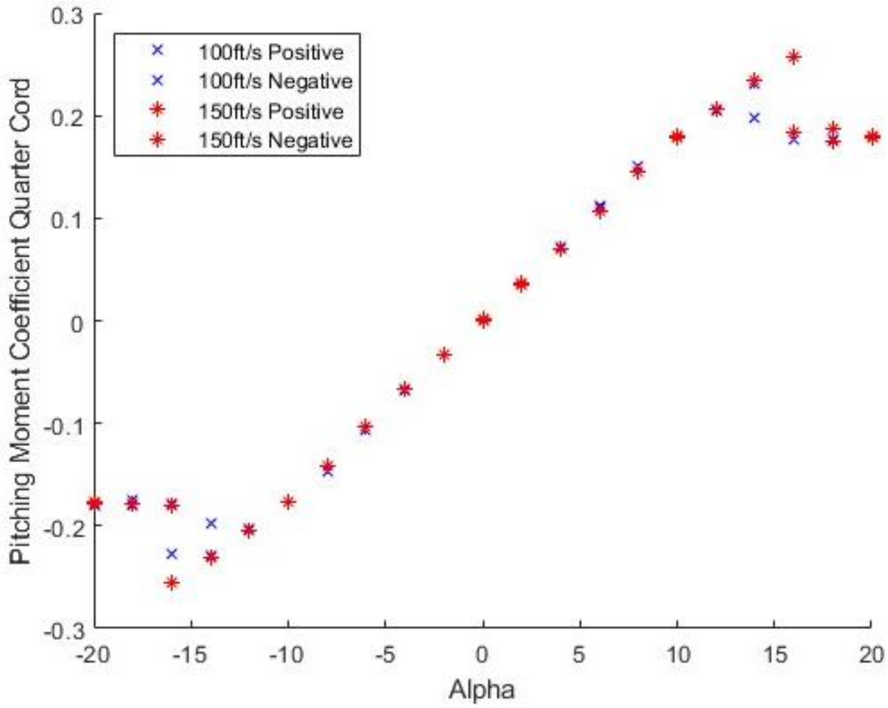

Figure 6. Pitching moment vs Alpha

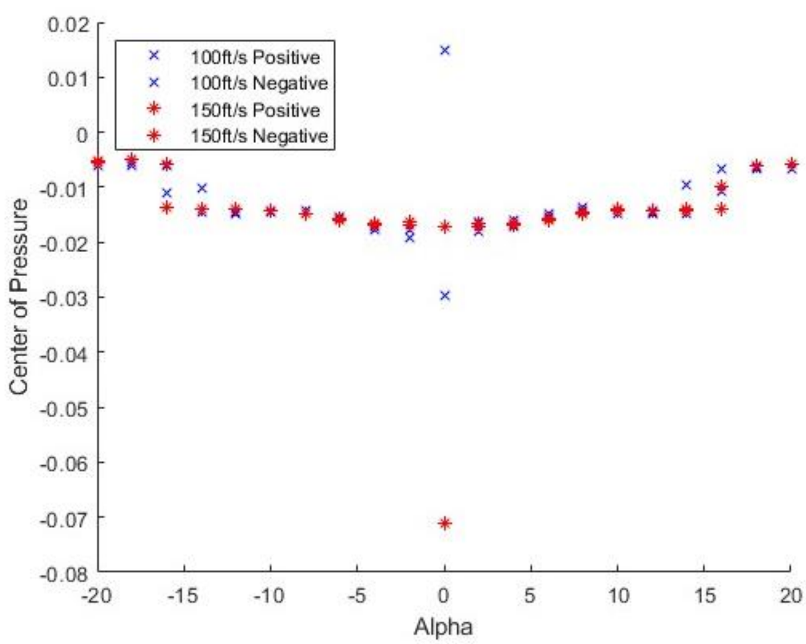

Figure 7. Aerodynamic center of pressure vs Alpha

As can be seen in Figure 7, the aerodynamic center of the airfoil remains relatively constant throughout the angle of attacks. However, near where the airfoil stalls, approximately 12 degrees, the center moves towards the front of the airfoil and is then located at the leading edge.

Conclusions

An airfoil can be characterized thoroughly through the use of a wind tunnel. By calculating the lift and drag coefficients across several angles of attack, the best lift to drag ratio can be found. Additionally, the pitching moment can be found at any point, usually at the quarter chord, as well as the aerodynamic center.

References

Department of Aerospace Engineering. *AE 315 Experimental Aerodynamics Lab 5*. Canvas

MATLAB Code

```
clear;
clc;
close all

%load the data into MATLAB
Group1_Pos0=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_142008_Sec18_Grp1_pos_0.csv');
Group1_Neg0=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_142654_Sec18_Grp1_neg_0.csv');
Group1_Pos100=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_143659_Sec18_Grp1_pos_100.csv');
Group1_Neg100=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_144425_Sec18_Grp1_neg_100.csv');
Group2_Pos0=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_153011_Sec18_Grp2_pos_0.csv');
Group2_Neg0=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_153703_Sec18_Grp2_neg_0.csv');
Group2_Pos150=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_154753_Sec18_Grp2_pos_150.csv');
Group2_Neg150=readtable('D:\Github\School\Aero Lab\Lab 5\Data\Sec18\040722_155535_Sec18_Grp2_neg_150.csv');


%Define Constants
Area=30.94*12;


%Find dynamic pressure for each case
Q_Pos100=Group1_Pos100.DynamicPressure-Group1_Pos0.DynamicPressure;
Q_Neg100=Group1_Neg100.DynamicPressure-Group1_Neg0.DynamicPressure;
Q_Pos150=Group2_Pos150.DynamicPressure-Group2_Pos0.DynamicPressure;
Q_Neg150=Group2_Neg150.DynamicPressure-Group2_Neg0.DynamicPressure;


%Find the CL for each case
LiftForcePos100=Group1_Pos100.WAFBCSide-Group1_Pos0.WAFBCSide;
LiftForceNeg100=Group1_Neg100.WAFBCSide-Group1_Neg0.WAFBCSide;
LiftForcePos150=Group2_Pos150.WAFBCSide-Group2_Pos0.WAFBCSide;
LiftForceNeg150=Group2_Neg150.WAFBCSide-Group2_Neg0.WAFBCSide;


CL_Pos100=LiftForcePos100./(Q_Pos100.*Area);
CL_Neg100=LiftForceNeg100./(Q_Neg100.*Area);
CL_Pos150=LiftForcePos150./(Q_Pos150.*Area);
CL_Neg150=LiftForceNeg150./(Q_Neg150.*Area);


%Find the CD for each case
DragPos100=Group1_Pos100.WAFBCDrag-Group1_Pos0.WAFBCDrag;
DragNeg100=Group1_Neg100.WAFBCDrag-Group1_Neg0.WAFBCDrag;
DragPos150=Group2_Pos150.WAFBCDrag-Group2_Pos0.WAFBCDrag;
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```
DragNeg150=Group2_Pos150.WAFBCDrag-Group2_Neg0.WAFBCDrag;

CD_Pos100=DragPos100./(Q_Pos100.*Area);
CD_Neg100=DragNeg100./(Q_Neg100.*Area);
CD_Pos150=DragPos150./(Q_Pos150.*Area);
CD_Neg150=DragNeg150./(Q_Neg150.*Area);

%Find CL/CD
CL_CDPos100=CL_Pos100./CD_Pos100;
CL_CDNeg100=CL_Neg100./CD_Neg100;
CL_CDPos150=CL_Pos150./CD_Pos150;
CL_CDNeg150=CL_Neg150./CD_Neg150;

%Find CMac/4
MomentPos100=(Group1_Pos100.WAFBCYaw-Group1_Pos0.WAFBCYaw)./(Q_Pos100*Area*12);
MomentNeg100=(Group1_Neg100.WAFBCYaw-Group1_Neg0.WAFBCYaw)./(Q_Neg100*Area*12);
MomentPos150=(Group2_Pos150.WAFBCYaw-Group2_Pos0.WAFBCYaw)./(Q_Pos150*Area*12);
MomentNeg150=(Group2_Neg150.WAFBCYaw-Group2_Neg0.WAFBCYaw)./(Q_Neg150*Area*12);


Moment4Pos100=MomentPos100+CL_Pos100*0.25;
Moment4Neg100=MomentNeg100+CL_Neg100*0.25;
Moment4Pos150=MomentPos150+CL_Pos150*0.25;
Moment4Neg150=MomentNeg150+CL_Neg150*0.25;



%Find Center of pressure vs Alpha
xcpnorm_Pos100=0.25-Moment4Pos100./CL_Pos100;
xcpnorm_Neg100=0.25-Moment4Neg100./CL_Neg100;
xcpnorm_Pos150=0.25-Moment4Pos150./CL_Pos150;
xcpnorm_Neg150=0.25-Moment4Neg150./CL_Neg150;

hold on

%CL vs Alpha
%plot(Group1_Pos100.Yaw,CL_Pos100,"x","Color","B")
%plot(Group1_Neg100.Yaw,CL_Neg100,"x","Color","b")
%plot(Group2_Pos150.Yaw,CL_Pos150,"*",'Color','r')
%plot(Group2_Neg150.Yaw,CL_Neg150,"*",'Color','r')
%xlabel("Alpha")
%ylabel("CL")
%legend("150ft/s Positive","150ft/s Negative","100ft/s Positive","100ft/s
Negative","Location","Northwest")

%CD vs Alpha
%0plot(Group1_Pos100.Yaw,CD_Pos100,"x","Color","B")
%plot(Group1_Neg100.Yaw,CD_Neg100,"x","Color","B")
%plot(Group2_Pos150.Yaw,CD_Pos150,"*","Color","r")
%plot(Group2_Neg150.Yaw,CD_Neg150,"*","Color","r")
%xlabel("Alpha")
%ylabel("CD")
%legend("100ft/s Positive","100ft/s Negative","150ft/s Positive","150ft/s
Negative","Location","North")
```

```
%CL vs CD
%plot(CD_Pos100,CL_Pos100,"x","Color","B")
%plot(CD_Neg100,CL_Neg100,"x","Color","B")
%plot(CD_Pos150,CL_Pos150,"*","Color","r")
%plot(CD_Neg150,CL_Neg150,"*","Color","r")
%xlabel("CD")
%ylabel("CL")
%legend("100ft/s Positive","100ft/s Negative","150ft/s Positive","150ft/s
Negative","Location","best")

%CL/CD vs Alpha
%plot(Group1_Pos100.Yaw,CL_CDPos100,"x","Color","b")
%plot(Group1_Neg100.Yaw,CL_CDNeg100,"x","Color","b")
%plot(Group2_Pos150.Yaw,CL_CDPos150,"*","Color","r")
%plot(Group2_Neg150.Yaw,CL_CDNeg150,"*","Color","r")
%xlabel("Alpha")
%ylabel("CL/CD")
%legend("100ft/s Positive","100ft/s Negative","150ft/s Positive","150ft/s
Negative","Location","Northwest")

%Quarter Cord Pitching Moment vs Alpha
%plot(Group1_Pos100.Yaw,Moment4Pos100,"x","Color","B")
%plot(Group1_Neg100.Yaw,Moment4Neg100,"x","Color","B")
%plot(Group2_Pos150.Yaw,Moment4Pos150,"*","Color","r")
%plot(Group2_Neg150.Yaw,Moment4Neg150,"*","Color","r")
%xlabel("Alpha")
%ylabel("Pitching Moment Coefficient Quarter Cord")
%legend("100ft/s Positive","100ft/s Negative","150ft/s Positive","150ft/s
Negative","Location","Northwest")

%Center of pressure vs Alpha
plot(Group1_Pos100.Yaw,xcpnorm_Pos100,"x","Color","B")
plot(Group1_Neg100.Yaw,xcpnorm_Neg100,"x","Color","B")
plot(Group2_Pos150.Yaw,xcpnorm_Pos150,"*","Color","r")
plot(Group2_Neg150.Yaw,xcpnorm_Neg150,"*","Color","r")
xlabel("Alpha")
ylabel("Center of Pressure")
legend("100ft/s Positive","100ft/s Negative","150ft/s Positive","150ft/s
Negative","Location","Northwest")
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